US/UK Sensor-To-Shooter Multinational C4 Interoperability Study
Force-On-Force Effectiveness Methodology

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Abstract

This paper documents the simulation-based methodology currently being used by the US Army TRADOC Analysis Center (TRAC) to measure the effects on overall combat effectiveness of command and control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) systems and architectures and their interoperability among joint and multinational forces. This methodology has been successfully applied to Army, joint, and multinational studies. The latest of these studies, the *US/UK Sensor-To-Shooter Multinational C4 Interoperability Study Force-On-Force Analysis*, was an effort to measure the value (in terms of force-on-force combat effectiveness) of enhancing the interoperability between US and UK forces. This paper presents the results of this US/UK study, as a case study, to illustrate the capabilities of this methodology. The overall objective of the US/UK study was to develop a multinational US/UK system and operational architecture that applies to fixed-wing (FW) and call-for-fire (CFF) precision engagements and to decisive maneuver operations. The purpose of the TRAC portion of the study was to provide a force-on-force analysis to the US Joint Staff, so they could make multinational interoperability recommendations to the US Joint Requirements Oversight Council and the UK Ministry of Defence. This paper focuses on the operational-level, force-on-force analysis of the alternative US/UK interoperability architectures for the FW/CFF portion of the study.

1. Introduction

The information age has re-emphasized and refocused the need for the US services and their allies to be able to share timely information among each other and is the catalyst behind the recent revolution in military affairs. Indeed, all four US services are now designing their force structures, unit compositions, and systems to leverage the anticipated benefits brought about by the information age. One of the keys to success on the battlefield of the information age is interoperability. This applies to how well the US services interoperate among themselves and how well the US interoperates with its allied and coalition partners. The force that can best move information around the battlefield and directly use it to enable a wider variety of its information and weapon systems will most likely win on the battlefield of the future.

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2. **Background**

Joint Vision 2010 established the framework for the evolution of the US Armed Forces in a challenging and uncertain future. It provides an operational template for how the US Armed Forces can channel the vitality of their people and leverage the technological opportunities to achieve new levels of effectiveness in joint warfighting. Joint Vision 2010 plainly states, *"The nature of modern warfare demands that we fight as a joint team. This was important yesterday, is essential today, and will be imperative tomorrow."* However, it is not enough just to be joint when conducting future operations. As pointed out in Joint Vision 2010, we must find the most effective methods for integrating and improving interoperability with allied and coalition partners because history, strategy, and recent experience suggest that the US will usually work in consort with its friends and allies in nearly all future operations.

Information and technology will have enormous impacts on all military forces. While successful adaptation of new and improved technologies has the potential to increase specific capabilities, the failure to understand and adapt could lead today's military forces into premature obsolescence. Since a long range precision engagement capability, combined with a wide range of delivery systems, is emerging as a key factor in future warfare, the Joint Staff commissioned a family of studies on the information requirements for precision targeting and engagements. This family of five studies is known as the Sensor-To-Shooter (STS) studies and is defined in Figure 1.

Study	**Title**
STS I	Sensor-to-Shooter I: Intelligence, Surveillance, Reconnaissance Joint Interoperability and Connectivity Analysis
STS II	Sensor-to Shooter C4 Architecture Analysis
STS III	Sensor-to Shooter Precision Engagement C4ISR Architecture Analysis
STS IV	Sensor-To-Shooter Battle Management C4ISR Architecture Analysis
STS V	United States and United Kingdom Multinational C4 Interoperability Study

Figure 1. Sensor-To-Shooter Family of Studies

The Sensor-To-Shooter series of studies began in 1994 with *Sensor-to-Shooter I: Intelligence, Surveillance, Reconnaissance Joint Interoperability and Connectivity Analysis.* STS I recommended investments for jointly linking intelligence, surveillance, and reconnaissance (ISR) sensors to all services. In 1995, STS II: *Sensor-to Shooter C4 Architecture Analysis* identified investments required to support three precision strike weapons (i.e., the Joint Direct Attack Munition (JDAM), the Joint Stand-Off Weapon (JSOW), and the Army Tactical Missile System (ATACMS)). In 1996-97, STS III: *Sensor-to Shooter Precision Engagement C4ISR Architecture Analysis* identified joint communication links and pathways required to implement aspects of Joint Vision 2010. STS III proposed specific investments to improve the mission areas of suppression of enemy air defenses, close air support, operational maneuver from the sea, brigade/regiment deliberate attack, and theater air defense. STS IV: *Sensor-to Shooter Battle Management C4ISR Architecture Analysis* identified investments to increase force-on-force effectiveness by improving the common operational picture (COP) / common tactical picture (CTP), parallel dissemination of targeting and other information, and joint weapon / target pairings. STS V: *United States and United Kingdom Multinational C4 Interoperability Study* examined the requirements for interoperability between US and UK forces conducting a combined operation. Specifically, STS V analyzed the impact of three levels of interoperability between the two forces in terms of their ability to conduct fixed-wing air missions (i.e., close air support and air interdiction) and call-for-fire missions with artillery and naval surface fire support. Results from the force-on-force analysis conducted by TRAC for this US/UK study will be used throughout this paper as examples of the methodology presented.

3. **Statement of the Problem**

Measuring the impact of interoperability on combat outcomes has proven to be quite challenging to the analytical community. Rarely are such analyses taken beyond the performance level. Many times decision-makers are provided a plethora of facts on the improved performance of weapon and information systems enabled by enhanced interoperability (e.g., increased number of messages, reduction in time to transmit messages, higher probability of hit, etc.). However, they are not always presented with commensurate facts on whether these performance increases actually improve the overall force-level combat outcomes. This paper presents a simulation-based methodology that measures the effects of performance increases in terms of overall combat effectiveness. TRAC successfully used this methodology on a variety of US Army, Joint Chiefs of Staff, and multinational studies focusing on C4ISR and interoperability including STS IV and STS V.

4. **General Methodology**

The goal of C4ISR and interoperability studies should be to provide the decision maker with information on both the effects on system performance and what impacts they have on operational effectiveness, usually in terms of combat outcomes. This requires a methodology that can provide an analysis that can distinguish operational effectiveness from performance. While performance and operational effectiveness are closely related, performance is the degree to which a particular system operates in order to accomplish its designed tasks. Operational effectiveness is typically measured in force attributes such as the ability of the force to accomplish its mission or the amount of losses a force can inflict on its adversary. Of course, this methodology requires an analytical tool that addresses the capabilities under investigation in enough detail that their performance measurably effects operational effectiveness.

A general methodology used by TRAC to accomplish this is presented at Figure 2. This methodology is consistent with the North Atlantic Treaty Organization (NATO) *Code of Best Practice on the Assessment of C2*. The methodology has four groupings of tasks that are color-coded in the figure. These groupings are called axes and in some instances can be worked concurrently. In addition, the tasks are color-coded to indicate which tasks TRAC typically

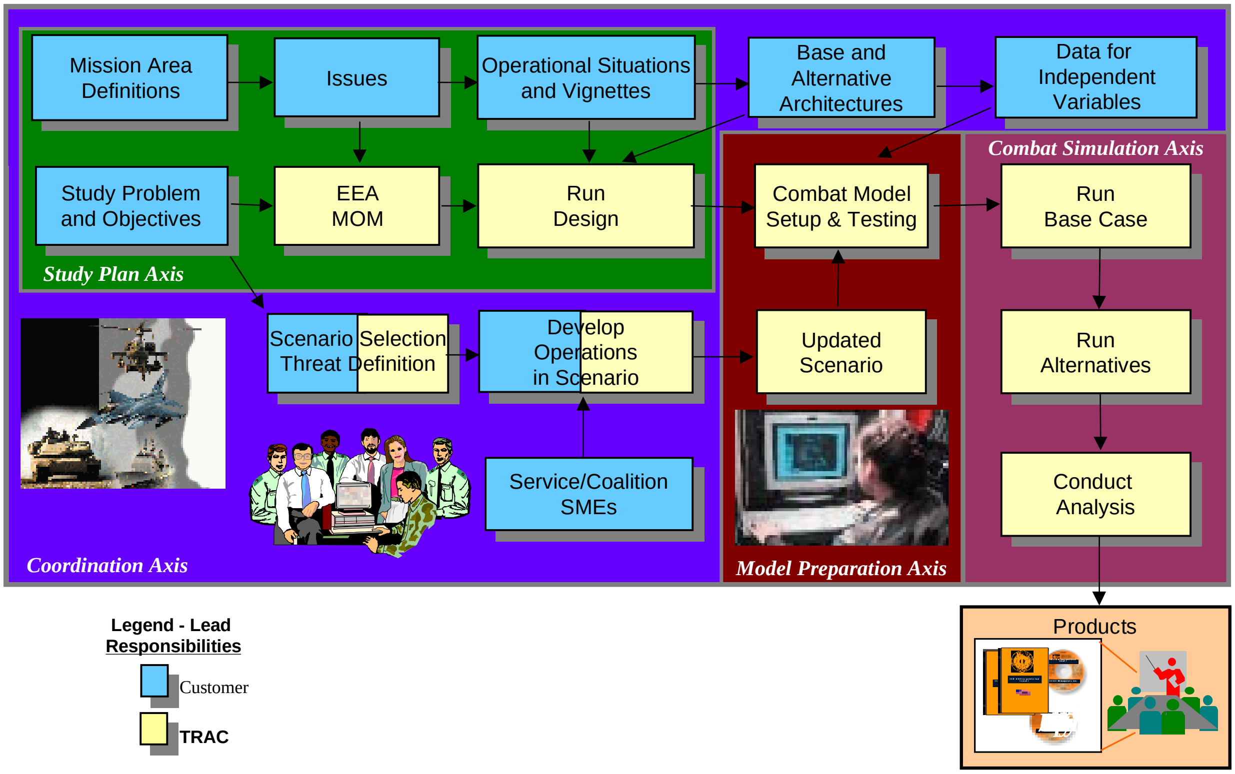

Figure 2. General Methodology

performs and which tasks the customer should typically perform or at least invest a significant amount of intellectual capital.

4.1 ***Study Plan Axis***

Every successful analysis begins at the same place – *problem definition*. The best source for this definition is the study's customer. However, sometimes the exact problem to be addressed is not absolutely clear. When that is the case, it is crucial to work with the customer until everyone clearly understands the problem and its associated issues. Upon definition of the study issues by the customer, they are decomposed into the essential elements of analysis (EEA). In turn, the EEA are further decomposed it into measures of merit (MOM), also known as measures of performance (MOP) and measures of effectiveness (MOE). Concurrently, analysts work with the customer to scope the context of the analysis in terms of the mission areas and the operational situations to be addressed.

This effort is formally documented in a study plan. The main components of a study plan include problem definition, issues, scope, study methodology, responsibilities of the study participants, and schedule. The study methodology contains the study issue decomposition into the EEA, the definitions of the MOM and their relationships to the EEA, the study alternatives (usually defined by the customer), specification of the analytic tools, and the run design. Perhaps the most crucial aspect, other than problem definition, to a successful study is the development of the run design. Specifically, it is the definition of the *independent variables* of the run design. The capabilities being studied (e.g., interoperability) must be defined as independent variables and the relationships of the capabilities being studied to the independent variables must be clearly understood and quantifiable. If this step is not done well, then a sound analysis is in jeopardy. Often, this step is more art than science.

4.2 *Coordination Axis*

Coordination with the study customer and other study participants is done throughout all the axes; the tasks in Figure 2 placed in the blue coordination axis are tasks that require inputs from sources outside of the analytic organization doing the study. Usually, the scenario requires a fair amount of coordination to establish the major theaters desired and to develop operational concepts, tactical maneuver, artillery and naval surface fire support, and fixed-wing support. In addition, threat operations require coordination with the proper threat community subject matter experts (SME). Other study participants (e.g., contractors supporting the customer) involved in various aspects of the study may provide data for the independent variables of the run design. Multinational studies require coordination with allies or coalition partners for their inputs in all of these areas.

4.3 *Model Preparation Axis*

Once the tasks on the study plan axis and coordination axis are completed, the tasks on the model preparation axis can be accomplished. Since this is a simulation-based methodology, these tasks relate to the proper preparation of a combat simulation for the desired analysis. The first step is to implement the scenario in the simulation's database for the base case run. At this point, separate databases varying the independent variables that define each alternative per the run design may also be prepared. Finally, checkout runs are made with the model to ensure the databases are properly prepared and to verify any model code modifications made for the study operate as intended. Any verification, validation, and authentication (VV&A) required for the study is accomplished at this time.

4.4 *Combat Simulation Axis*

Once the model preparation tasks are completed, the actual production runs can be made. The base case run is made first. Since the analyses done with combat simulations are almost always comparative in nature, the base case typically serves as the basis for these comparative analyses. Once the base case is completed, the alternative runs are made. Each alternative is usually compared to the base case. However, in some instances, alternatives may be compared to each other.

The analysis typically uses the MOM defined in the study plan and measured in the production runs of the base case and alternatives. Invariably, some of these MOM will not show measurable differences among the alternatives, while other MOM will evolve during the analysis from differences measured between run results that were not anticipated *a priori*. Nonetheless, trends and insights from comparative analyses of the MOM are used to evaluate the essential elements of analysis. The EEA, in turn, are used to address each issue per the methodology established in the study plan.

4.5 ***Results***

The results are typically prepared in both briefing and written report formats. Depending on the customer's requirements, briefings of initial insights can be ready shortly after the production runs conclude. A comprehensive briefing of the results usually requires 2-4 weeks of analysis. Again, depending on the customer's requirements, written products range from a scripted briefing to a technical report and are provided on paper, compact disk, or both.

5. **A Case Study**

The latest of the Sensor-To-Shooter family of studies, the *US/UK Sensor-To-Shooter Multinational C4 Interoperability Study Force-On-Force Analysis*, will be used as a case study to illustrate the general methodology described above. The US Joint Staff and the UK Ministry of Defence sponsored the study. The principal analytic organizations in the US were TRAC, the Defense Information Systems Agency (DISA), and Joint Staff contractors. The Defence Evaluation and Research Agency (DERA) conducted the analysis for the UK.

5.1 ***Objective***

The overarching objective of the US/UK interoperability study was to develop a multinational US/UK system and operational architecture that applied to fixed-wing and call-for-fire precision engagements and to decisive maneuver operations. The study objective, as defined by the Joint Staff, was to develop a proposed architecture that supports the Chairman, Joint Chiefs of Staff Joint Vision 2010. The analysis of this architecture intended to lead to programmatic recommendations for US command and control, communications, and computer (C4) systems and for UK command, control, and intelligence (C2I) and communications and information systems (CIS) to achieve a functional level of multinational system interoperability. The objective of the TRAC portion of the US/UK interoperability study was to provide an operational-level, force-on-force analysis of the alternative US/UK interoperability architectures. This analysis identified differences in US/UK multinational battle outcomes over a range of interoperability alternatives. These results assisted the Joint Staff in recommending investments to improve US C4 and UK C2I CIS architectures and multinational communications interoperability.

5.2 ***Issues***

The overarching issue assigned to TRAC by the Joint Staff to address in this study was: *"What is the contribution to overall force effectiveness of improvements in multinational US C4 and UK C2I CIS interoperability?"* The focus of this analysis was on the contribution of US/UK interoperability to fixed-wing and call-for-fire precision engagements. TRAC decomposed the study issue into six essential elements of analysis to fully address the overarching issue. These EEA were:

- EEA 1. Does the Combined Joint Task Force (CJTF) accomplish its mission?
- EEA 2. Can the CJTF conduct a follow-on mission?

- EEA 3. Does the CJTF effectively shape the battlespace?
- EEA 4. Does the CJTF win the decisive battle?
- EEA 5. Does the multinational division conduct effective CFF missions?
- EEA 6. Does the multinational division receive effective FW missions?

5.3 *Levels of Information System Interoperability*

The main factor investigated in the US/UK study was the level of information systems interoperability (LISI). The scale depicted in Figure 3 shows a means to quantify interoperability. The Office of the Secretary of Defense through the C4ISR Architecture Working Group (AWG) established the LISI reference model as a means to quantify information interoperability. The C4ISR AWG developed LISI to ensure the promulgation of, and adherence to, unambiguous department-wide information technology and standards. Within the Department of Defense, the LISI reference model is an important element in the effort to achieve the degree of interoperability needed for information superiority. The five LISI levels range from a low at the *isolated* level to a high at the *enterprise* level. The LISI reference model represents degrees of sophistication required to accomplish interactions among information systems. The use of levels 0 through 4[1] provides a discipline for describing the nature of information interaction among information systems. They characterize that interaction into the suite of information system capabilities (the computing environment) necessary to support the information flows in context with the operational need (e.g., timeliness, accuracy) and define the implementation rules for each system capability.

5.3.1 *Alternatives*

An assessment, using the LISI reference model, found that the current interoperability capabilities between US and UK forces were essentially at the *isolated* level or LISI 0. Although there are some systems that do have some rudimentary connectivity between the two forces, the force interoperability, when taken as a whole, was at LISI 0, because these systems generally require some sort of manual interface or liaison. Next, the study team determined just how high

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[1] LISI 0 - *Isolated*: Systems have no direct electronic connection. Data exchange between these systems typically occurs via either manual keyboard entry or an extractable common media format (e.g., diskette).
LISI 1 - *Connected*: Electronically linked systems. These systems conduct peer-to-peer exchange of homogeneous data types, such as simple “text,” e-mail, or fixed graphic files. Generally, LISI 1 systems allow decision-makers to simply exchange files with one another.
LISI 2 - *Functional*: Systems are distributed, i.e., they reside on local networks that allow system to system passing of complex, heterogeneous data sets (e.g., annotated images, maps with overlays). They contain formal data models (logical and physical), but generally each program defines its own physical data model. Interoperable programs agree only on the logical data models. Generally, decision-makers share fused information between systems or functions.
LISI 3 - *Domain*: Wide area networks connect and integrate systems and allow multiple users to access data. Independent applications share information at this level. Systems can implement business rules and processes to facilitate direct database-to-database interactions, such as those required supporting database replication servers. Individual applications at this level may share central or distributed data repositories.
LISI 4 - *Enterprise*: Systems can operate using a distributed global information space across multiple domains. Multiple users can access and interact with complex data simultaneously. Data and applications are fully independent and distributed throughout this space to support information fusion. Advanced forms of collaboration (the virtual office concept) are possible. Data has a common interpretation regardless of form, and applies across the entire enterprise. This diminishes the need for redundant, functionally equivalent applications since applications can share as readily as data at this level.

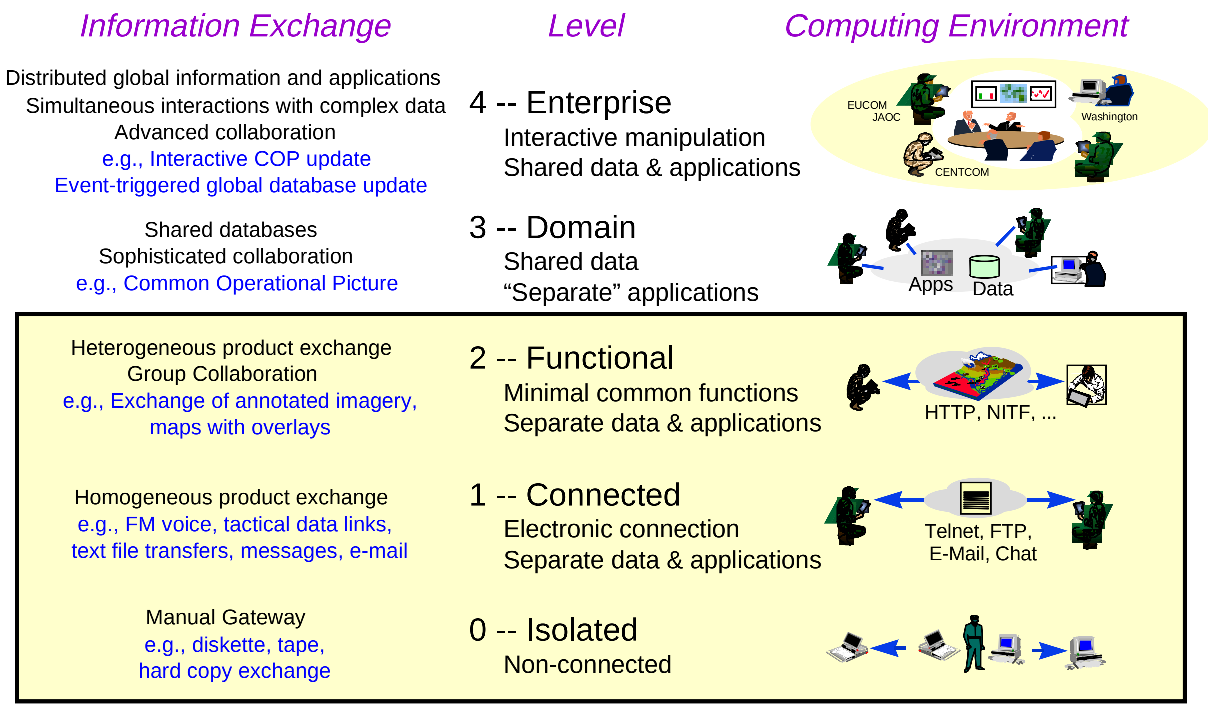


Figure 3. Levels of Information System Interoperability

a level US and UK force interoperability could reasonably expect to achieve in the 2010 time frame. As part of this process, the study team examined the interoperability levels that the US services were attempting to achieve. The latter level was determined to be the *functional* level, or LISI 2. Systems with separate data and applications and minimal common functions characterize LISI 2. Again, there will be systems that do achieve the *domain* level, or LISI 3, but the US services as a whole are projected to be at LISI 2. Thus, this force-on-force analysis, as indicated in the yellow highlighted area in Figure 3, concentrated on the system and procedural alternatives required for the interoperability between the two forces to progress from an *isolated* level (LISI 0) circa 2000 through the *connected* level (LISI 1) circa 2006 to the *functional* level (LISI 2) circa 2010.

5.3.2 *Interoperability-enabled Capabilities*

The C4ISR system and procedural alternatives needed by the US and UK to advance from LISI 0 to LISI 2 were the focus for the explicit US/UK CJTF interoperability-enabled capabilities explored. Each higher level of the LISI reference model embodied a verifiable boost in capabilities over the previous level of system-to-system relationships. This was with respect to the data moved, the applications that exploit the data, the requisite infrastructure, and the policies and processes for information management.

Performance-level analysis provided estimated latency times consisting of the time intervals required for information transmission, processing, and decision-making for various actions and activities. The force-on-force modeling and analysis effort used these latency times to quantify the US/UK CJTF C4ISR interoperability-enabled capabilities. Specifically, the times were those required to conduct fixed-wing sorties, naval surface fire support call-for-fire missions, artillery call-for-fire missions, parallel dissemination, and common relevant operational picture development. These latency times based on the three LISI levels of interoperability, were the parameters of the independent variables of the run design. Thus, the latency data quantified the CJTF C4ISR interoperability capabilities for the base case and the two improved interoperability alternatives. The steps taken to develop the latency data are illustrated in Figure 4.

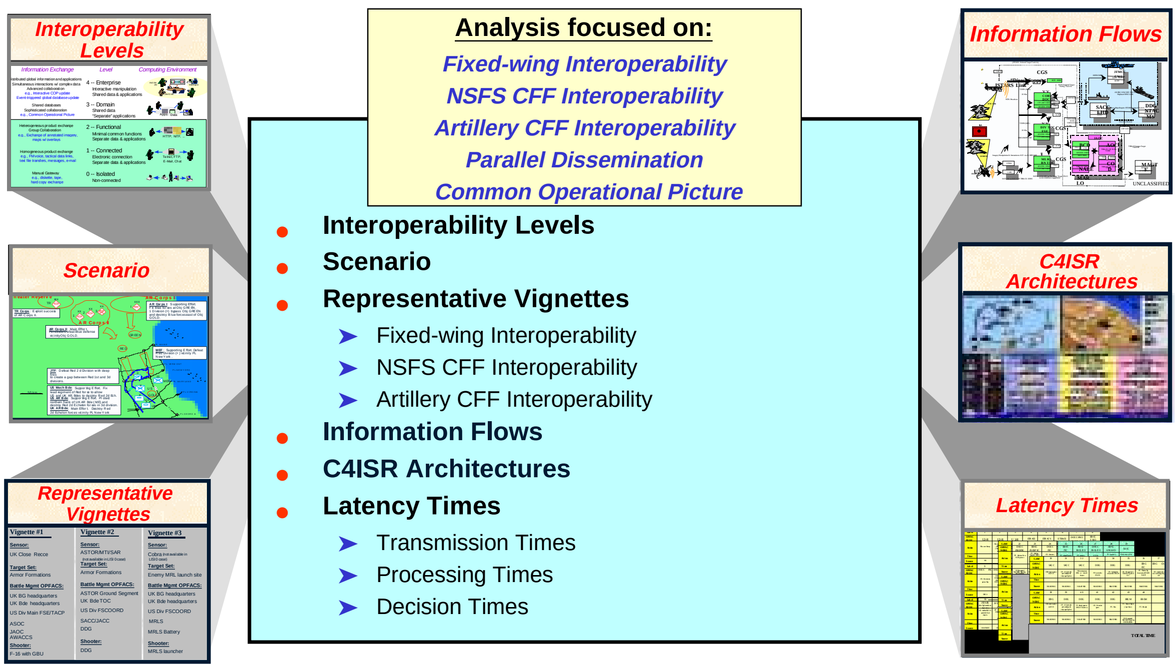


Figure 4. Interoperability-enabled Capabilities

5.3.2.1 *Scenario and Representative Vignettes.*

Once the LISI levels were established, a scenario was chosen to serve as the context of the study. Then, specific operational situations (OPSIT), or vignettes, were defined for the base case and alternative (LISI 0 through LISI 2) interoperability architectures. Each OPSIT was set up to generate air sorties, naval surface fire support, or artillery missions that would originate in the UK and go to an appropriate US shooter for prosecution. The Joint Staff, through contractors, used detailed performance analysis to screen the many alternatives for enhancing CJTF C4ISR interoperability. This enabled them to select only the most promising for force-on-force analysis.

5.3.2.2 *Information Flows.*

Each vignette required the three steps on the right side of Figure 4. The first step in developing a vignette was to determine a target, a suite of sensors that could detect it, and provide that detection to the UK forces. Then, in order to exercise US/UK CJTF interoperability capabilities, an appropriate US shooter was then selected to prosecute the target. The next step in the information flow process was to identify the actions and activities at each battle management node needed to detect the target, to process the intelligence for the common operational picture or for the target mission, and to fire the mission. Next, a variety of different ways to route the information among the battle management nodes were evaluated for each alternative level of interoperability. An example of an information flow for a naval surface fire support vignette is shown in Figure 5. In this vignette, a UK Airborne Standoff Radar (ASTOR) detects moving armor formations. The detection is reported through the various battle management nodes and the target is handed-off to a US destroyer for prosecution. Similar vignettes were developed for fixed-wing sorties and artillery call-for-fire missions.

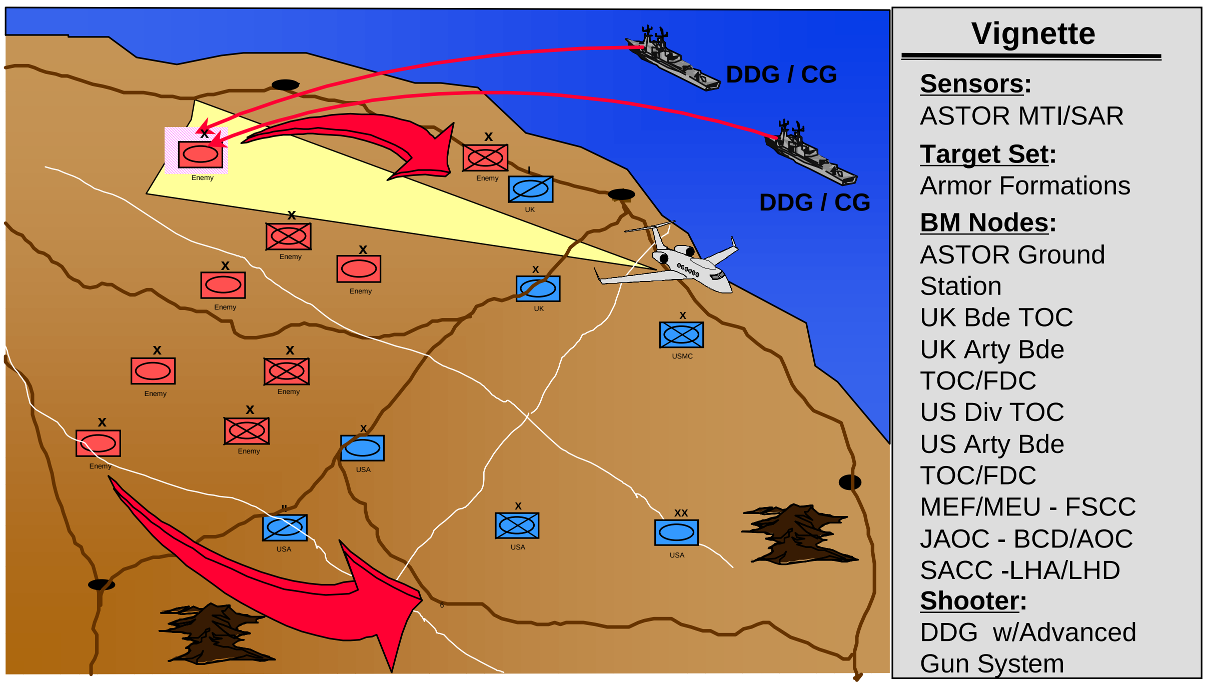


Figure 5. NSFS vignette information flow.

5.3.2.3 *C4ISR Architectures*

Once the targets, sensors, and shooters were established and the battle management nodes were identified, the system architecture required to progressively move the COP intelligence or target mission information from the UK sensor to the US shooter prosecuting the mission was determined. Each alternative examined these system architectures for potential enhancements by technology-enabled capabilities. An example architecture for naval surface fire support is depicted in Figure 6. The block of information for each battle management node in the figure specifies the section of the organization (white), the battle management system (yellow), the hardware (orange), the data structure (gray), and the communications devices (blue) used to process the information. Many such architectures, some with varying paths for the information to take, were developed and evaluated through performance analysis to determine the most promising designs for each alternative level of interoperability. Sets of such architectures were developed and analyzed for each of the interoperability-enabled capabilities examined.

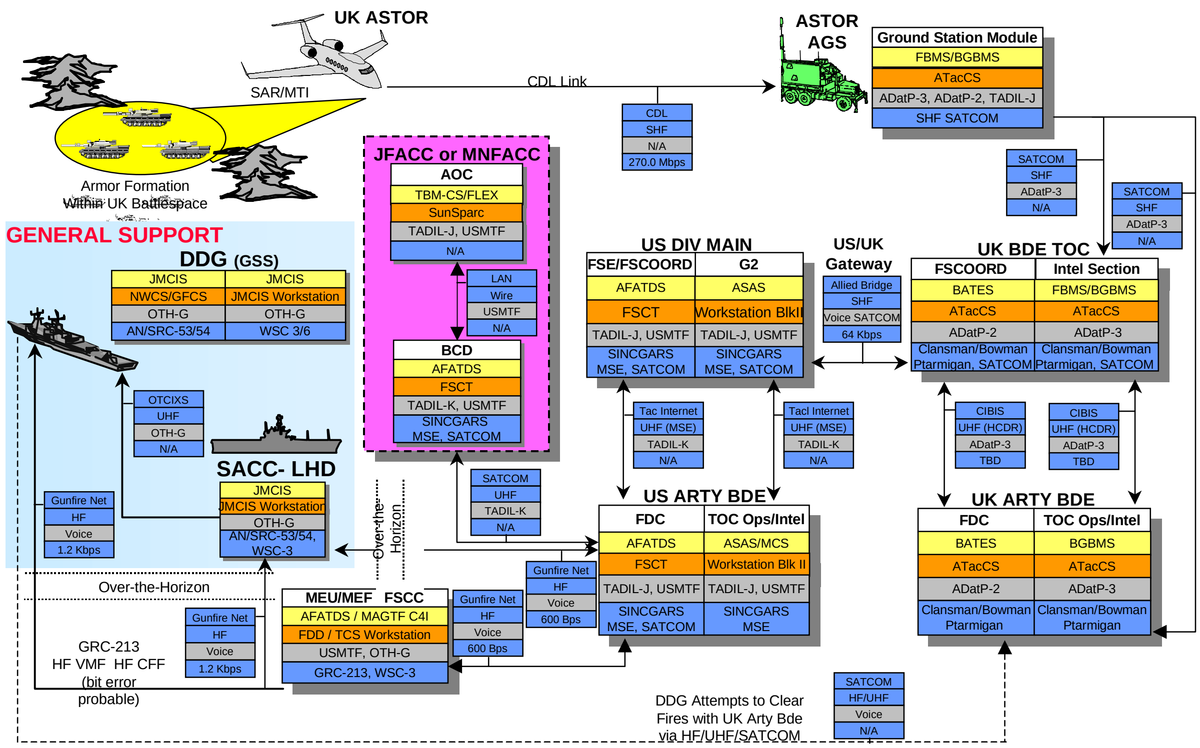


Figure 6. C4ISR system architecture for naval surface fire support.

5.3.2.4 *Latency Times*

Finally, latency times for each activity including processing times, decision times, and transmission times resulted from the analysis of the system architectures. The most promising architectures, in the form of these latency times were evaluated in the next step of the process – the effectiveness analysis. The individual latency times were aggregated into data meaningful to the force-on-force combat simulation. These aggregated latency times were the parameters of the interoperability-enabled capabilities, which served as the independent variables of the run design.

5.3.3 *Run Design*

The run design is presented in Figure 7. As defined along the top of the figure, the run design consisted of a base case and two alternatives. LISI 0 constituted the base case. The two alternatives were LISI 1 and LISI 2. The left column of the figure specifies the independent variables used to quantify fixed-wing interoperability, call-for-fire interoperability, parallel dissemination, and common operational picture. The chart specifies one or more parameters within each of these independent variables. The entries under each LISI level depict the aggregated latency times developed during the performance analysis.

	Base Case (LISI Level 0)	Alternative 1 (LISI Level 1)	Alternative 2 (LISI Level 2)
FW Interoperability			
Cross-nation pass times for multinational FW missions *Tactical Air Request Net (TARN)*	Voice Only FW Mission Time	Voice using JTRS FW Mission Time	Voice JTRS and Link 16 data FW Mission Time
CFF Interoperability			
Cross-nation pass times for multinational FS missions *BATES – AFATDS*	LNO at Div TOC USA FS Mission Time USN FS Mission Time	CNR circuit bridge at brigade level using JTRS USA FS Mission Time USN FS Mission Time	WIN-T to VEDS LAS at Bde level using SATCOM / universal modem USA FS Mission Time USN FS Mission Time
Parallel Dissemination (PD)			
ASTOR – JSTARS feed to US and UK	No AGS available at UK brigade	UK with AGS/ASTOR ASTOR LMU Time	UK with AGS/ASTOR + Link-16 ASTOR LMU Time
Shooters receive last minute update from UK FO	USA FS LMU Time USN FS LMU Time	USA FS LMU Time USN FS LMU Time	USA FS LMU Time USN FS LMU Time
COBRA feed to AFATDS	No connection	CFF Mission Time LMU Time	CFF Mission Time LMU Time
Common Operational Picture (COP)			
MNF pass COP *MCS to FBMS/BGBMS*	LNO at Div TOC Blue Position Update Time Threat Position Update Time	CNR circuit bridge at Div TOC Blue Position Update Time Threat Position Update Time	WIN-T VEDS LAS link at Bde TOC Blue Position Update Time Threat Position Update Time

Figure 7. Run Design

5.3.3.1 *Fixed-wing Interoperability*

Referring to Figure 7, FW interoperability uses cross-nation pass times as the independent variables for CJTF FW sorties. FW cross-nation pass time data for each LISI level represent the times required for a UK air control party or battalion air liaison officer to make a request, for the request to travel up through the required echelons and systems, for the request to be tasked to an aircraft, and for a pilot to fly to the target area and receive a 9-line brief. Note that as the interoperability is enhanced from LISI 0 through LISI 2, the times required to perform these tasks are reduced. The three values represent the three echelons from which a supporting aircraft could come:

- An air mission from aircraft allocated directly to the UK brigade
- An additional air mission re-allocated to the UK brigade from the US division
- An additional air mission re-allocated to the UK brigade from the CJTF

5.3.3.2 *Call-for-fire Interoperability*

CFF interoperability also used cross-nation pass times as the independent variables for CJTF fire support missions passed to the US Advanced Field Artillery Tactical Data System (AFATDS) from the UK Battlefield Artillery Target Engagement System (BATES). CFF interoperability data from each LISI level represent the time required for a forward observer (FO) to make a request, for the request to pass up through the queues at each echelons, for the firing unit to be tasked, and for the firing to commence. Values for US naval surface fire support (NSFS) are given as well as values for US Army artillery CFF missions. The two Army values represent the two echelons, which could prosecute the CFF mission:

- US division artillery
- Corps-level (CJTF) artillery

5.3.3.3 ***Parallel Dissemination***

Figure 7 shows parallel dissemination used last minute updates (LMUs) and cross-nation interoperability for two specific sensor systems as the independent variables. The sensor systems included the UK Counter Battery Radar (COBRA) system and the UK Advanced Ground Station (AGS). The AGS is capable of receiving data from either a UK ASTOR or US Joint Surveillance Target Attack Radar System (JSTARS). At LISI 0 (circa year 2000), no AGS would be available to the UK forces, and, thus, the UK force would not have any capability to directly interoperate with JSTARS. Figure 7 reflects AGS availability at LISI 1 and LISI 2, with decreasing latencies. Also, at LISI 0, limited interoperability disallowed any sensor-to-shooter connection between the COBRA and US shooters. At LISI levels 1 and 2, this connection existed with decreasing latencies. LMUs decreased with enhanced interoperability and represent the latency of target positional (track) data. Note that a LMU of 0 equates to eyes-on-target at trigger pull. For artillery systems this means a FO is observing the target and adjusting the fire. The values presented were associated with existing and potential sensor-to-shooter connections and targeting data links (e.g., AFATDS, Link-16, etc.).

5.3.3.4 ***Common Operational Picture***

The independent variables for COP were the frequency of how often the two forces shared information on friendly and enemy ground situations using the US Maneuver Control System (MCS) and the UK Formation Battle Management System (FBMS) or the UK Battle Group Battle Management System (BGBMS). Shown in Figure 7 are the times required to update and post on the situation map (SITMAP) the positions of friendly and enemy units at each of the three LISI levels. Note that as interoperability is improved, there is a significant reduction in the time required to accomplish these tasks.

5.4 ***Context***

The scenario used in the study was developed with inputs from the Joint Staff, the US services, and the UK. This scenario pitted a Combined Joint Task Force defending against an attacking enemy force. The CJTF ground forces consisted of an Army division and two US Marine regimental landing teams. The Army division was composed of two US brigades and had operational control of a UK brigade. US Air Force, US Navy, and UK Royal Air Force fixed-wing aircraft and US naval surface fire support supported the CJTF ground forces. The threat consisted of four divisions attacking the CJTF, which was in defensive positions. The CJTF conducted a counterattack with the UK brigade and one US Army brigade during the operation.

5.4.1 *Assumptions*

- In order to ensure changes in combat outcomes were a result of multinational interoperability enhancements, all alternatives held weapon systems and munitions constant. Thus, differences in measured outcomes can be attributed to differences in the amount and the flow of information across the battlefield.
- This study evaluated US and UK technologies and systems. It was assumed that the necessary US C4I architecture and UK C2I CIS were in place to support the new technologies.
- US/UK forces did not operate in isolation; they were part of a larger theater operation. Applicable multinational, Combined Joint Task Force, and joint operations set the conditions for the employment of the division and were defined by established US, allied, and joint doctrine, definitions, and tactics, techniques and procedures (TTP). This specifically included UK inputs on doctrine and operations as defined by UK AWP 0-10 and by UK subject matter experts.
- The threat represented was a highly capable, yet realistic, force. The enemy force consisted of those technologies and systems determined to be available in 2010. The enemy force featured large numbers of tanks, infantry, armored fighting vehicles, self-propelled artillery, and supporting mobile equipment. This included a comprehensive arsenal of air defense weapons: antiaircraft artillery, missiles, and vehicle-mounted machine guns.
- The USAF Studies and Analysis group prepared the air tasking order (ATO). In agreement with the UK, the study team added the Royal Air Force sorties to the existing ATO.
- US Navy forces consisted of two carrier battle groups (CVBG) and two surface action groups (SAG). Each SAG contained three ships, each with one 5" gun capable of firing the Extended Range Guided Munition (ERGM). One of the ships also had an Advanced Gun System.

5.4.2 *Limitations and Constraints*

- This study focused only on operations conducted during war as defined by Joint Pub 3-09 and Joint Pub 3-09. This analysis did not address theater-related issues.
- US Navy Advanced Gun System and Extended Range Guided Munition rounds were constrained to the equivalent of one magazine replenishment for the 30 hour battle.
- Army Tactical Missile System and Sense and Destroy Armor (SADARM) rounds were constrained to the planned procurement levels for those munitions.

- The analysis investigated employment of the CJTF in a single scenario. Results of this study may or may not be applicable in other scenarios.
- The analytical approach implicitly represented dismounted infantry, civil affairs, public affairs, and psychological operations. Analysts considered these capabilities in defining the scenario's starting situation.

5.5 *Analytic Tool*

The third critical component of a successful study is the *analytic tool*. It must be sensitive to variations in the independent variables. This means that the analytic tool must model the phenomena under investigation in sufficient detail to measure changes in outcomes as they are varied. In studies where information is under investigation the analytic tool must model the information-related processes in sufficient detail that differences in the arrival of information impacts simulation results.

Vector-In-Commander (VIC) was the combat simulation used to conduct this analysis. The main characteristics of VIC are presented in Figure 8. VIC is the US Army's and US Marine Corps' accredited combat simulation for division and corps operations. The resolution of entities varies with application, but typically is at the battalion for maneuver units, individual naval ships, flights of two fixed-wing aircraft, platoons for attack helicopters, batteries (sometimes launchers) for artillery and air defense units, and intelligence sensors at the platform-level. VIC utilizes approved US Army, Navy, Air Force, Marine, and Joint Staff data sources for weapons effects, intelligence gathering capabilities, and communications performance. A team of military and

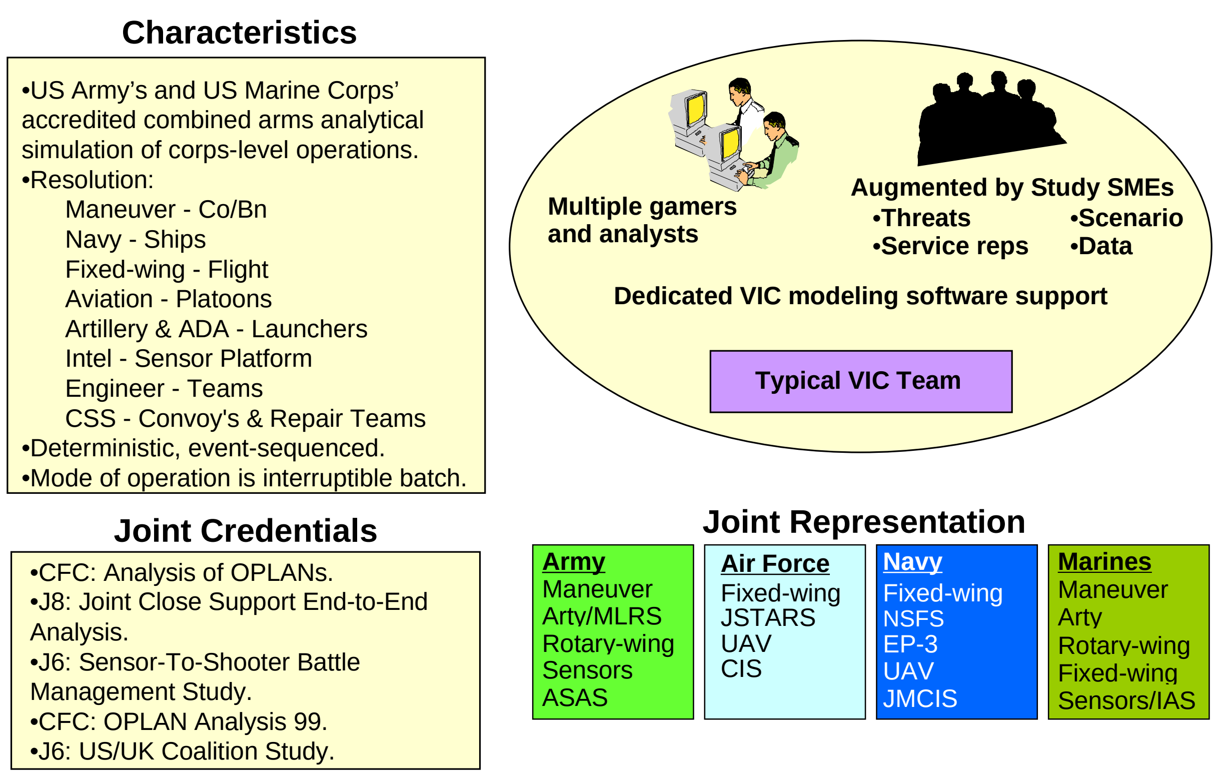


Figure 8. Vector-In-Commander.

civilian analysts at TRAC operates and maintains VIC. The subject matter experts for this study included Joint Staff personnel, US Army, Navy, Air Force, and Marine personnel, UK participants, the US/UK Joint Work Group, and defense contractors under contract to the Joint Staff.

5.5.1 *Joint Representation*

In recent years, VIC has received significant modifications to portray Joint operations. Specifically, VIC represents joint organizations (e.g., Joint Task Force (JTF), Joint Force Land Component Commander (JFLCC), Joint Force Air Component Commander (JFACC), Joint Force Maritime Component Commander (JFMCC), etc.) as specific entities on the battlefield and provides them with their own perception of the battlefield. These perceptions reside in each service's respective intelligence processor (i.e., Army All Source Analysis System, Marine Corps Intelligence Analysis System, Navy Joint Maritime Command Information System, and Air Force Combat Intelligence System). That service's sensors and the sensors of other services feed the intelligence processors where appropriate. VIC has incorporated the Joint Targeting Manual, which establishes the joint targeting doctrine for all the services, to allocate missions to artillery, naval surface fire support, and fixed-wing aircraft.

5.5.2 *Multinational Representation*

TRAC expanded the joint representations in VIC to include UK forces, which provided an explicit UK perception of the battlefield. The UK intelligence processors represented were the BGBMS and FBMS. The communications paths and the latency times associated with them were included in the independent variables of this study.

5.5.3 *Credentials*

TRAC has used VIC for joint analysis on numerous occasions. Projects accomplished in the recent past include the analysis of operations plans (OPLAN) for the Combined Forces Command (CFC) in Korea. CFC has since requested TRAC to conduct similar analyses on the new OPLANs during 1999-2000. VIC was used to conduct the *Joint Close Support End-to-End Analysis* for the Joint Staff in 1997. VIC was also used to determine the contributions to overall combat effectiveness in the *Sensor-To-Shooter Joint Battle Management Study Force-On-Force Analysis* for the Joint Staff in 1998, and, of course, the *US/UK Sensor-To-Shooter Multinational C4 Interoperability Study Force-On-Force Analysis* in 1999.

5.6 *Results*

The force-on-force results were measured using the measures of merit defined in the study plan. These MOM typically are organized into two groups: measures of performance of the force and measures of effectiveness of the force. The MOP generally examine the areas of completeness, timeliness, accuracy, and quality of the information provided to various components of the force have as a result of the performance of their C4ISR systems. The MOE, on the other hand, measure the impact the information had on the combat capability of the force in terms of mission accomplishment, ability to inflict damage on the enemy, ability to survive the operation, and the like. The MOP and MOE presented below are examples for how enhanced interoperability can change force-level performance and impact a force's effectiveness.

5.6.1 *Performance Measures*

Since this study examined interoperability, the MOP addressed the typical kinds of performance measures that are examined in the C4ISR class of studies. Specifically, the completeness, the timeliness, the accuracy, and the quality of the perceptions of various levels of the force were measured for each level of interoperability investigated. In addition, the impact on FW and CFF performance in terms of the number of sorties and missions prosecuted were also examined.

5.6.1.1 *Completeness*

Figure 9 contains charts for the percent of the enemy ground forces in the US division Tactical Operations Center's (TOC) All Source Analysis System and the UK brigade TOC's Battle Group Battle Management System. Except for an initial delay of 105 minutes, which corresponds to the update interval for enemy units at LISI 0 (see the run design at Figure 7), the two graphs appear almost the same. After the first update between the two forces' intelligence processors, there is very little difference in the percentage of enemy units known in the US division TOC and the UK brigade TOC.

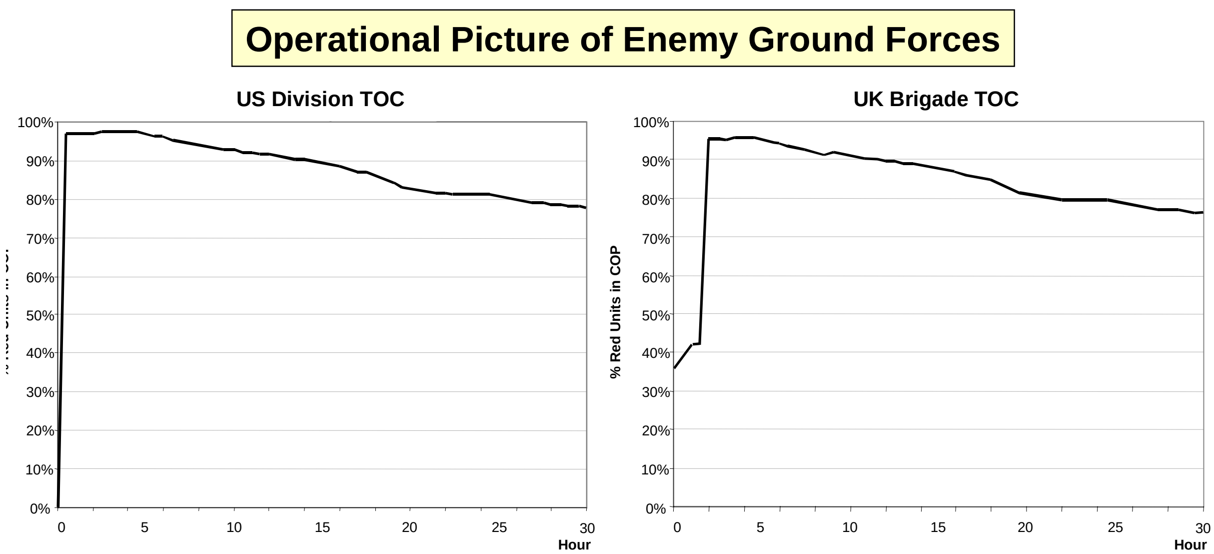


Figure 9. Completeness at LISI 0.

5.6.1.2 *Timeliness*

This somewhat surprising result for completeness is clarified by looking at the timeliness of the Intel reports in the respective intelligence processor databases. Figure 10 contains the same charts presented in Figure 9, except that they have been color-coded for timeliness of the reports in terms of the time since the latest detection and report of the enemy ground units. Dark green indicates the percent of units detected and reported within the last 15 minutes, light green

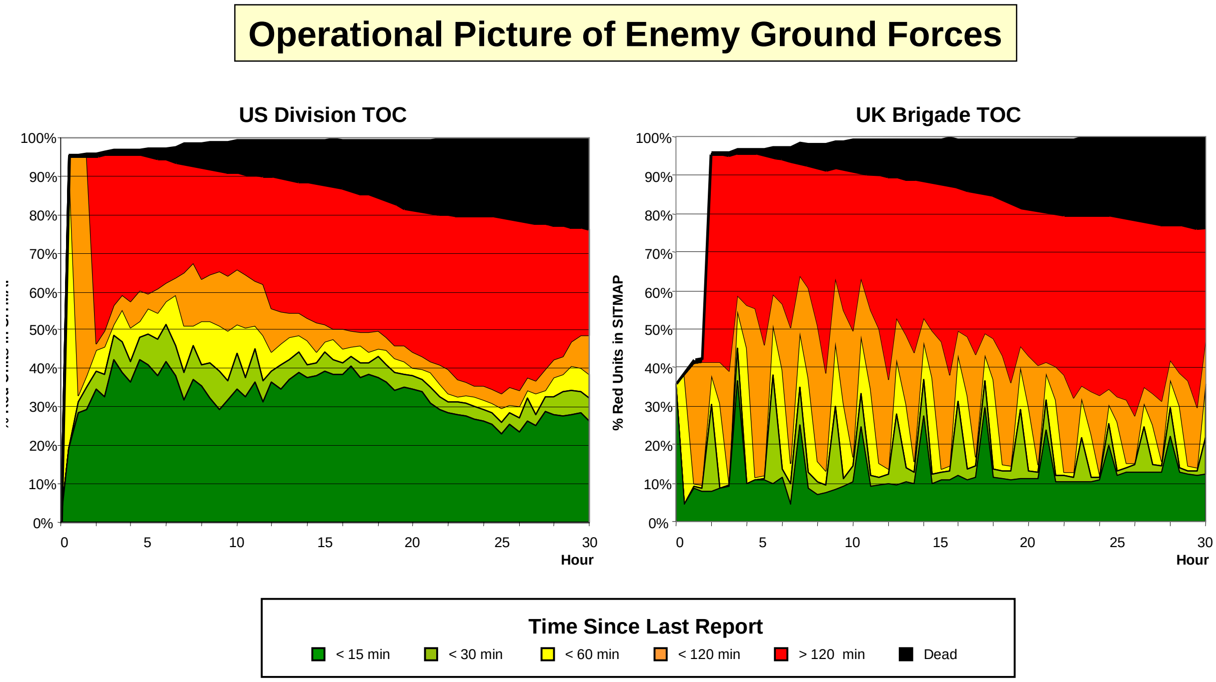


Figure 10. Completeness and timeliness at LISI 0.

indicates within the last 30 minutes, yellow indicates within the last hour, and orange indicates within the last 2 hours. Red indicates more than two hours, and black indicates dead enemy units. Analysis of the timeliness of detections shows a considerable difference in the operational picture between the US and UK. So, although the lines indicating completeness in Figure 9 show little difference, Figure 10 definitely shows that the information on enemy ground units in the UK brigade TOC is much less timely than in the US division TOC. Figure 11 presents the same

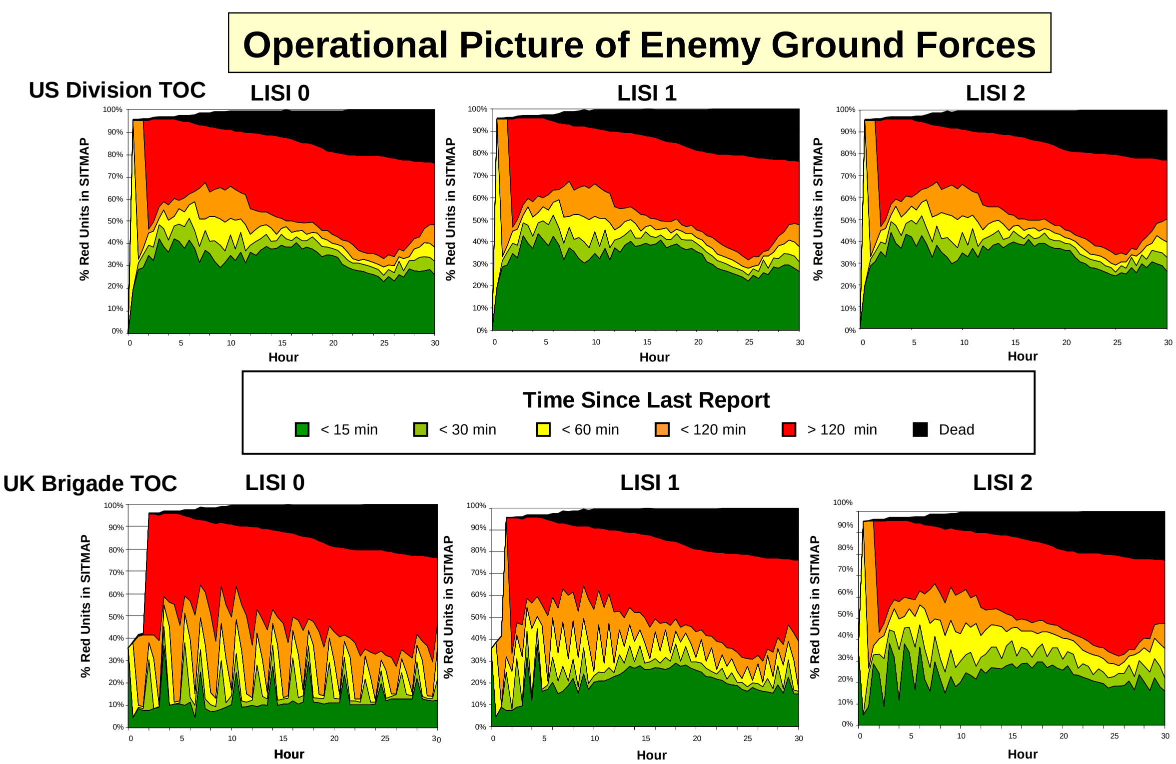


Figure 11. Completeness and timeliness for all three LISI levels.

charts at all three LISI levels. Inspection of the US division TOC charts leads to the conclusion that, in this operation, interoperability with the UK did not measurably improve its perception of the enemy units. However, inspection of the UK brigade TOC shows a definite increase in the percentage of units that are detected and reported in a more timely fashion. This is readily apparent comparing the increase in the percent of enemy units detected and reported within the last 15 minutes (dark green). In fact, the UK brigade plot at LISI 2 is starting to look like the US division plot.

5.6.1.3 *Accuracy*

Similar to timeliness, the completeness can be color-coded by the accuracy of the detections at given points in time. Figure 12 depicts plots of the location accuracy of the information on detected enemy units in the respective intelligence processors at the US division TOC and UK brigade TOC for the three LISI levels under investigation. The location accuracy was computed by comparing the location of each enemy unit in the intelligence database against ground truth. The categories chosen correspond to ranges of target location errors that facilitate attack by certain classes of weapons. The percentage of units located to within 50 meters of their actual location has a dark green color. This range of targeting accuracy allows attack with dumb munitions and global positioning system (GPS) - guided artillery munitions. The next target location error indicates units located to between 50-300 meters, which has a light green color. Smart munitions having small footprints can attack targets with this range of accuracy. The third target location error is the yellow area between 300-2000 meters. This range is associated with

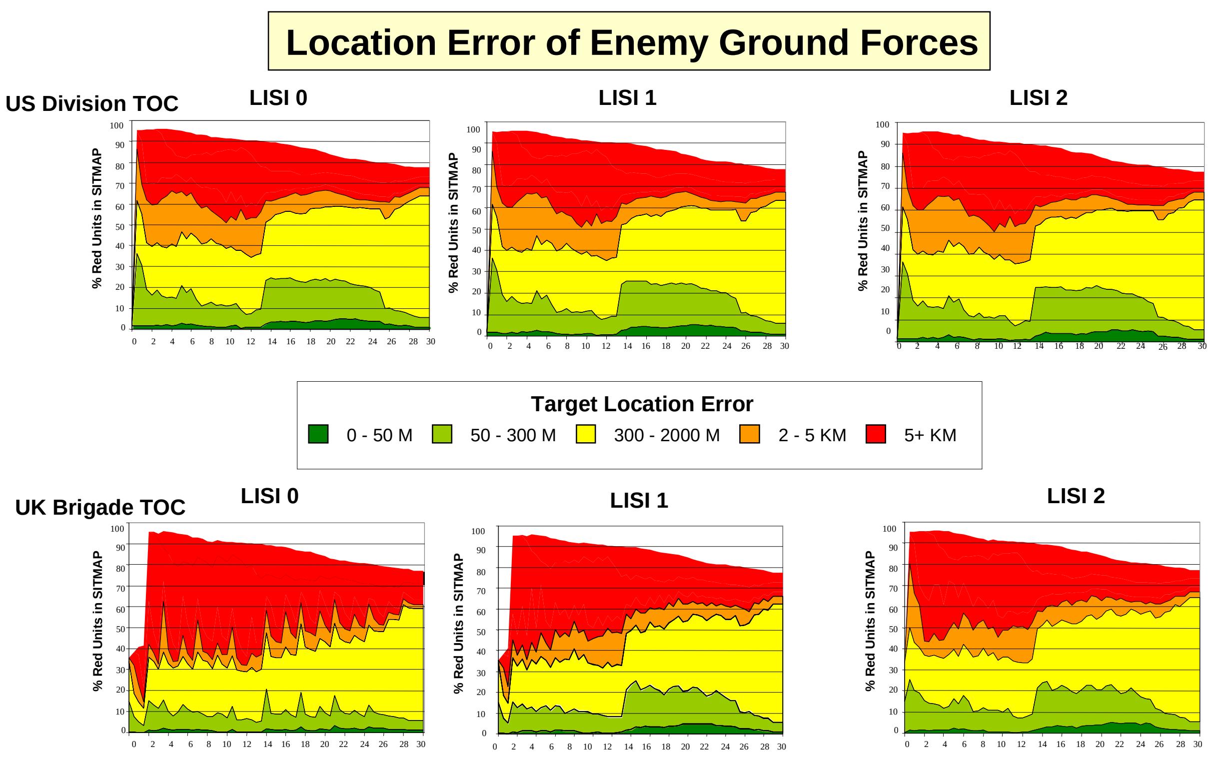


Figure 12. Completeness and accuracy for all three LISI levels.

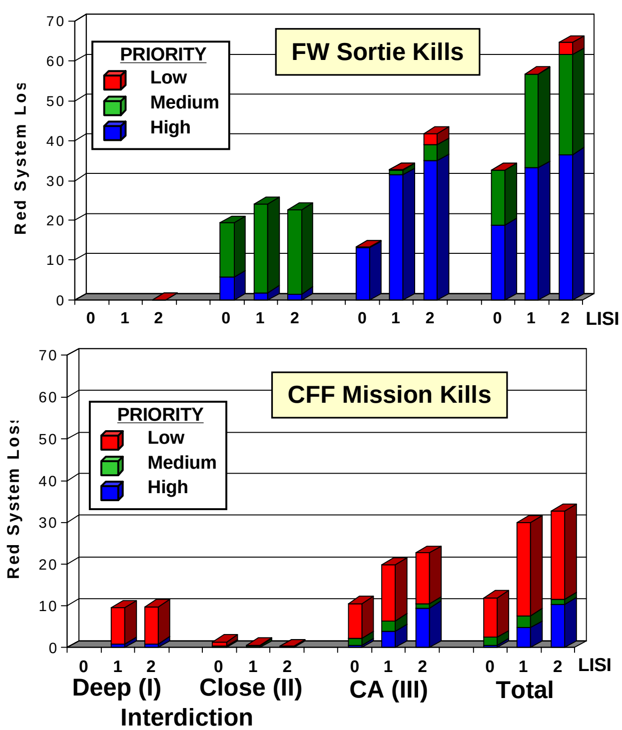
smart munitions with large footprints or piloted aircraft searching for targets. Of course, piloted aircraft can engage the more accurate targets as well. Only piloted aircraft can engage units within the 2-5 kilometer category. However, at this level of accuracy, there is a high probability the pilot will not locate the correct target. The red target location error (above 5 kilometers) is not feasible for targeting.

When inspecting this chart, one must consider two things. One is that the enemy units are conducting an attack. Accordingly, they are rarely stationary. It does not take long for a unit to move 50 meters. Thus, as one might expect, there are few units that are located at the highest level of accuracy. Second, the positional data in the intelligence processor is not typically used for precision targeting. The color-code scheme based on targeting accuracy was chosen, nonetheless, as a standard means to determine the accuracy of the information in the databases and to be able to measure and observe any changes to that data as interoperability was enhanced.

As with the timeliness measures, the accuracy did not seem to change for the US division as interoperability with the UK brigade was enhanced. Again, the accuracy of the UK brigade's database measurably improved as interoperability was enhanced.

5.6.1.4 *Quality*

Figure 13 presents results on the numbers of high, medium, and low priority systems killed by fixed-wing sorties from US Air Force, US Navy, and US Marine Corps aircraft and call-for-fire missions from US artillery and naval surface fire support. The right side of the figure shows the priority of the systems for three of the phases of the operation. The charts on the left show the



	High	Medium	Low
I	WMD SA-10/15 MRL (LR) Armor (TAI) C2 (Div+)	C2 (Bde-) Arty MRL(SR) SAM(-)	Armor(-) AAA Helo LOG
II	WMD SA-10/15 MRL (LR) Arty C2 (Div+)	C2 (Bde-) Armor MRL(SR) SAM(-)	AAA Helo LOG
III	WMD SA-10/15 MRL (LR) Arty Armor	C2 MRL (SR)	SAM (-) AAA Helo LOG

Figure 13. US CFF and FW kills in support of UK by priority.

number of kills by priority for each LISI level. Note the three columns on the right side of the charts. These are the total kills for all three phases. Examination of this data leads one to conclude that, as interoperability was enhanced, more enemy systems were killed and more of them were high priority targets. Thus, the enhanced interoperability provided more timely and accurate targeting, which enabled the engagement and destruction of more, higher quality targets.

5.6.1.5 ***US Support to UK***

Figure 14 presents the number of FW sorties and CFF (i.e., artillery and naval surface fire support) missions provided by the US in support of the UK force. It is readily apparent in Figure 14 that the number of both FW sorties and CFF missions increased significantly as the level of interoperability (LISI) was enhanced.

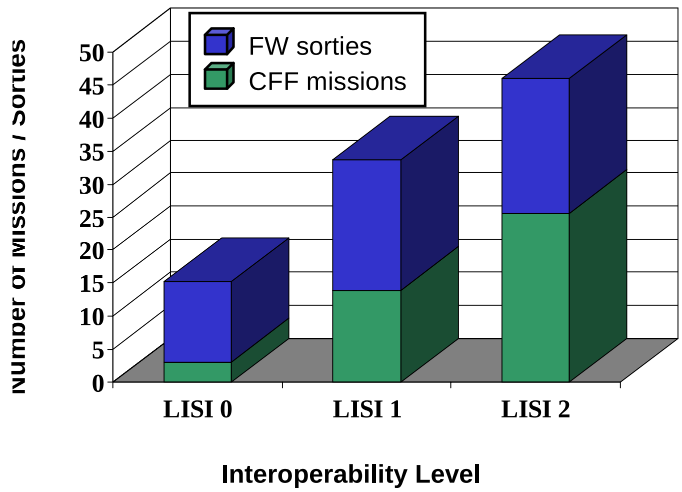


Figure 14. US FW sorties and CFF missions to UK.

5.6.2 ***Effectiveness Measures***

After measuring various performance enhancements and establishing that enhanced interoperability did improve force-level C4ISR performance with resultant increases in FW and CFF performance, next we turn to examining if these performance improvements made any measurable differences in the overall combat results. This is the classical "So what?" question. There are actually a large number of MOE to examine. The ones selected for the purposes of this paper were the numbers of effective missions, the enemy systems killed by UK and US shooters in support of the UK force, the number of enemy units halted during shaping operations, and the overall force effectiveness. Each of these was measured at all three interoperability levels.

5.6.2.1 ***Effective Missions***

Figure 14 shows that improved interoperability resulted in increases in the numbers of missions and sorties supporting the UK. One way to measure the effectiveness of these missions and sorties is to determine the percentage of them that engaged the original targets and inflicted some damage on those targets. Common reasons for an ineffective mission or sortie include not hitting the original target (for reasons such as the target moved or was already destroyed) or hitting the target, but

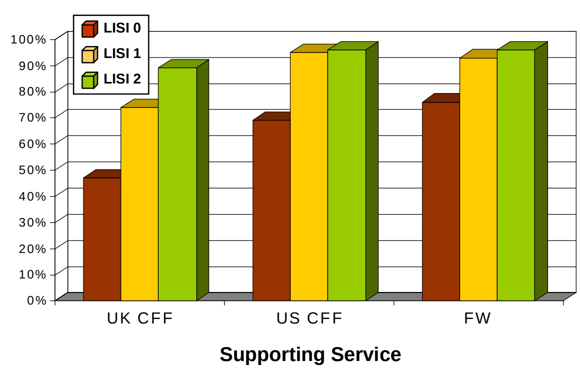


Figure 15. Effective FW sorties and CFF missions.

inflicting no damage. Note that many missions and sorties considered ineffective missions actually hit and damaged other targets. This MOE gives a sense of whether the sensor-battle management-shooter architecture can successfully attack the intended targets. Figure 15 presents a chart of the effective missions. The number of FW sorties and CFF missions presented in Figure 14 correspond to the right two groups of columns in Figure 15. Thus, not only are more sorties and missions being flown, but also they are engaging more of the targets for which the missions were originally generated. The left grouping of columns shows that the UK organic artillery also demonstrated improved effective missions because of the improved C4ISR performance enabled by enhanced interoperability.

5.6.2.2 *UK and US Support to UK*

After showing that enhanced interoperability has enabled more missions with a higher percentage of them being effective missions, the analysis looked to see if that caused a measurable difference on the battlefield. Figure 16 presents the number of "critical" enemy system losses for three categories of killers – UK CFF, US CFF, and US FW. In this analysis tanks, armored fighting vehicles, tube artillery, multiple rocket launchers, and C2 vehicles were classified as critical enemy systems. As can be deduced from inspection of Figure 16, enhanced interoperability significantly improved the ability of UK artillery, US artillery and naval surface fire support, and US and UK fixed-wing aircraft to destroy enemy critical systems.

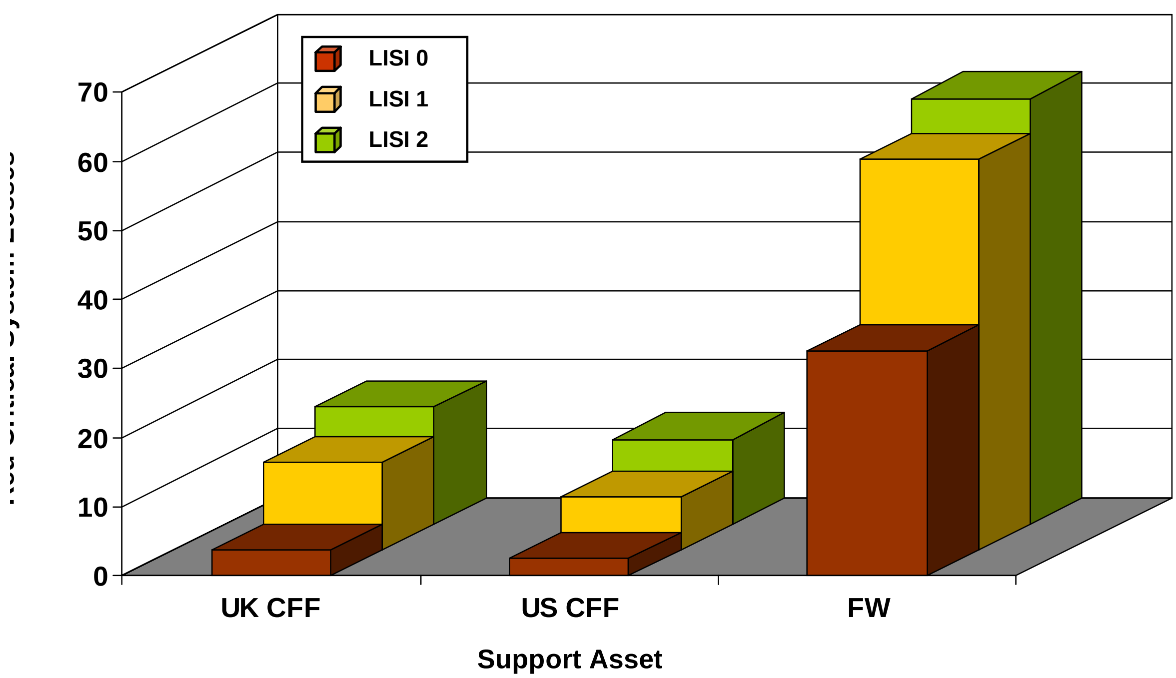


Figure 16. US and UK support to UK.

5.6.2.3 ***Shaping Operations***

Figure 17 depicts the number of maneuver and artillery battalions halted deep by the shaping operations for each level of interoperability investigated. Examination of the chart finds that the number of maneuver and artillery battalions halted steadily increased as interoperability was enhanced. The net effect of the shaping operations is that fewer enemy forces made it down to close with the US and UK forces. This should result in fewer US and UK losses.

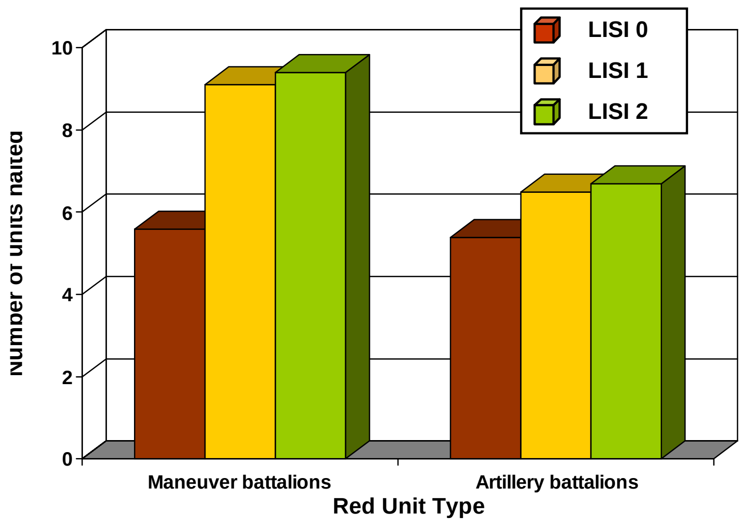


Figure 17. Shaping Operations.

5.6.2.4 ***Overall Force Effectiveness***

The ultimate "So what?" question is answered in terms of the overall force. In this case, did enhanced interoperability provide any measurable difference in the outcome of the battle? One typically first looks at mission accomplishment. In the scenario used for this analysis, the CJTF forces in the base case (LISI 0) accomplished the mission; so did both alternatives. So, further examination was necessary to determine if there was a measurable difference due to interoperability.

Enemy and friendly losses were next examined. They are presented in Figure 18 for four echelons of the force – the UK brigade, the counterattack force, the division, and the Combined Joint Task Force for each LISI level. In addition, for each of these echelons, the loss exchange

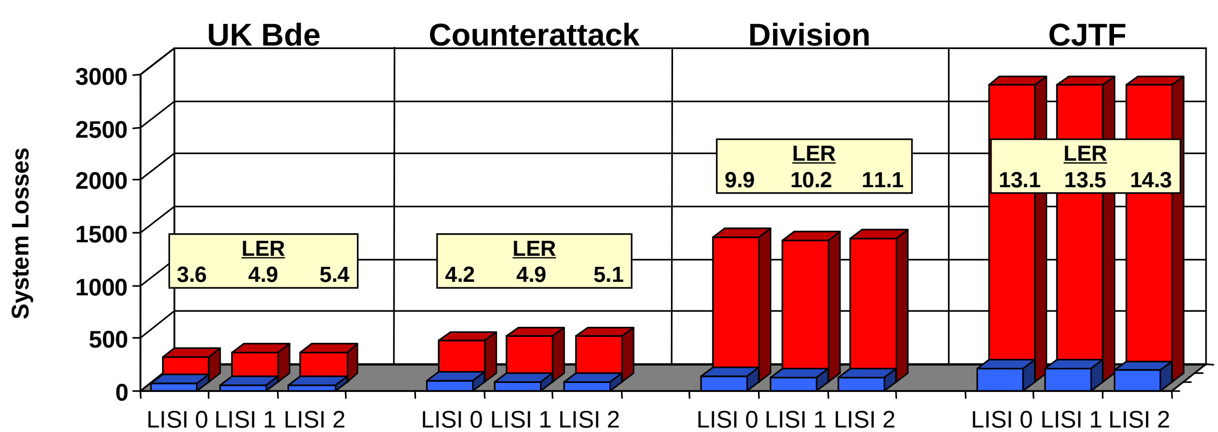


Figure 18. Overall force effectiveness.

ratio (LER) is shown for each level of interoperability. LER is the ratio of the enemy losses divided by friendly losses. Although it is difficult to discern from the chart, the enemy (red) losses increased at the lower echelons (UK brigade and counterattack force), but were relatively constant at the higher echelons (division and CJTF). However, friendly (blue) losses in general decreased. The LER is shown to steadily increase as interoperability was enhanced. The reduction in friendly losses (as interoperability was enhanced) was the principle contributor to the improvement in overall force effectiveness as measured by LER.

Examination of the LERs lead to the conclusion that the changes in interoperability had the greatest impact at the lower echelons. In retrospect, this makes sense. Recall that the changes in interoperability were made between the UK brigade and the US division. Accordingly, one would expect the highest payoff to be at that point. Figure 19 presents the LER data in a different format. Here the LERs are normalized to the LISI 0 value and presented as percent increases from that base case value. From Figure 19 it is evident that there are substantial increases in effectiveness at the LISI 1 and 2 levels of interoperability. Although the effects are dramatic at the lower levels, there is also a measurable improvement at the CJTF level.

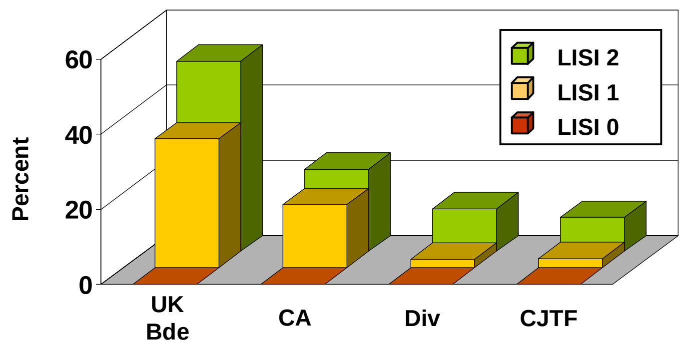


Figure 19. Percent increase in LER.

6. **Summary**

The methodology presented in this paper has been successfully used on numerous C4ISR and interoperability studies. Three critical elements are crucial to the successful application of this, or any other, analytical methodology. The first element is ***problem definition***. One must clearly understand the problem before it can be analyzed. Otherwise, you may analyze the wrong problem. The second element is the ***definition of the independent variables of the run design***. The capabilities being studied (e.g., interoperability) must be defined as the independent variables of the run design and the relationships of the capabilities being studied to the independent variables must be clearly understood and quantifiable. The third element is ***use of an analytic tool that is sensitive to variations in the independent variables***. The Vector-In-Commander model is such a tool. It is sensitive to changes in C4ISR parameters, including interoperability. Results from the *US/UK Sensor-To-Shooter Multinational C4 Interoperability Study Force-On-Force Analysis* provided concrete examples of both force-level C4ISR measures of performance and the corresponding force-level measures of effectiveness. By holding all munitions and weapons constant and varying only the way information was shared among units on the battlefield, there was consistent, measurable evidence that enhancing interoperability improved performance of C4ISR at the force-level, which resulted in increased force-level effectiveness.

7. Glossary

AAA	Antiaircraft Artillery
ADA	Air Defense Artillery
ADatP-2	Allied Data Protocol - 2
ADatP-3	Allied Data Protocol - 3
AFATDS	Advanced Field Artillery Tactical Data System
AGS	Advanced Ground Station (UK)
AOC	Air Operations Center
Arty	Artillery
ASAS	All Source Analysis System
ASTOR	Airborne Standoff Radar (UK)
ATacCS	Army Tactical Computer System (UK)
ATACMS	Army Tactical Missile System
ATO	Air Tasking Order
AWG	Architecture Work Group
BATES	Battlefield Artillery Target Engagement System (UK)
BCD	Battlefield Coordination Detachment
Bde	Brigade
BGBMS	Battle Group Battle Management System
BM	Battle Management
Bn	Battalion
C2I	Command, Control, and Intelligence
C4	Command, Control, Communications, and Computers
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CDL	Common Data Link
CENTCOM	US Central Command
CFC	Combined Forces Command
CFF	Call-For-Fire
CIS	Communication and Information System (UK)
CIS	Combat Intelligence System (US)
CJTF	Combined Joint Task Force
CNR	Combat Net Radio
Co	Company
COBRA	Counter Battery Radar (UK)
COP	Common Operational Picture
CSS	Combat Service Support
CTP	Common Tactical Picture
CVBG	Carrier Battle Group
DDG	Guided Missile Destroyer
DERA	Defence Evaluation and Research Agency (UK)

DISA	Defense Information Systems Agency
Div	Division
EEA	Essential Elements of Analysis
EP-3	US Navy Radar Aircraft
ERGM	Extended Range Guided Munition
EUCOM	US European Command
FBMS	Formation Battle Management System (UK)
FDC	Fire Direction Center
FDD	Floppy Disk Drive
FM	Frequency Modulation
FO	Forward Observer
FS	Fire Support
FSCC	Fire Support Coordination Center
FSCOORD	Fire Support Coordinator
FSCT	Fire Support Control Terminal
FSE	Fire Support Element
FTP	File Transfer Protocol
FW	Fixed-Wing
GFCS	Gunfire Control System
GPS	Global Positioning System
GSS	General Support Ship
HCDR	High Capacity Digital Radio
Helo	Helicopter
HF	High Frequency
HTTP	Hypertext Transfer Protocol
IAS	Intelligence Analysis System
Intel	Intelligence
ISR	Intelligence, Surveillance, and Reconnaissance
JAOC	Joint Air Operations Center
JDAM	Joint Direct Attack Munition
JFACC	Joint Force Air Component Commander
JFLCC	Joint Force Land Component Commander
JFMCC	Joint Force Maritime Component Commander
JMCIS	Joint Maritime Command Information System
JSOW	Joint Standoff Weapon
JSTARS	Joint Surveillance Target Attack Radar System
JTF	Joint Task Force
JTRS	Joint Tactical Radio System

KM	Kilometer
LAS	Local Area Subsystem
LER	Loss Exchange Ratio
LHA/LHD	Amphibious Assault Ship
LISI	Level of Information System Interoperability
LMU	Last Minute Update
LNO	Liaison Officer
LOG	Logistics Systems
MEF	Marine Expeditionary Force
MEU	Marine Expeditionary Unit
MCS	Maneuver Control System
MLRS	Multiple Launch Rocket System
MOE	Measures of Effectiveness
MOM	Measures of Merit
MOP	Measures of Performance
MRL	Multiple Rocket Launcher
MTI	Moving Target Indicator
NATO	North Atlantic Treaty Organization
NITF	News Industry Text Format
NSFS	Naval Surface Fire Support
NWCS	Navy Weapons Control System
OPLAN	Operations Plan
OPSIT	Operational Situation
OTH-G	Over the Horizon - Ground
SA-10/15	Surface to Air Missile Systems
SACC	Supporting Arms Control Center
SADARM	Search and Destroy Armor
SAG	Surface Action Group
SAM	Surface to Air Missile Systems
SAR	Synthetic Aperture Radar
SATCOM	Satellite Communications
SHF	Super High Frequency
SINCGARS	Single Channel Ground and Airborne Radio System
SITMAP	Situation Map
SME	Subject Matter Experts
STS	Sensor-To-Shooter
TADIL-J	Tactical Digital Information Link (Link-16)
TARN	Tactical Air Request Net
TBM-CS	Theater Battle Management System

TCS	Tactical Communications System
TOC	Tactical Operations Center
TRADOC	Training and Doctrine Command
TRAC	TRADOC Analysis Center
TTP	Tactics, Techniques, and Procedures
UAV	Unattended Aerial Vehicle
UHF	Ultra High Frequency
UK	United Kingdom
USA	US Army
USAF	US Air Force
USMC	US Marine Corps
USMTF	United States Message Text Format
USN	US Navy
US	United States
VEDS	Vehicle External Data System
VIC	Vector-In-Commander
VMF	Variable Message Format
VV&A	Verification, Validation, and Authentication
WIN-T	Warfighter Information Network – Terrestrial
WMD	Weapons of Mass Destruction